Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

C S A S | **S C C S**

Canadian Science Advisory Secretariat | **Secrétariat canadien de consultation scientifique**

Research Document 2008/027 | **Document de recherche 2008/027**

Not to be cited without permission of the authors *

Ne pas citer sans autorisation des auteurs *

Physical oceanographic conditions in NAFO Division 3P during 2007- potential influences on the distribution and abundance of Atlantic cod (*Gadus morhua*)

Conditions océanographiques physiques dans la division 3P de l'OPANO en 2007 – effets possibles sur la répartition et l'abondance de la morue (*Gadus morhua*)

E. B. Colbourne and E. F. Murphy

Science Branch
Fisheries and Oceans Canada
P. O. Box 5667
St. John's NL, Canada A1C 5X1

ISSN 1499-3848 (Printed / Imprimé)

Canada

ABSTRACT

Oceanographic data from NAFO Div. 3P during the spring of 2007 are examined and compared to previous years and the long-term (1971-2000) average. The data show anomalous cold periods in the mid-1970s and from the mid-1980s to the mid-to-late-1990s with temperatures up to 1°C below average and up to 2°C below the warmer values of the late 1970s and early 1980s. Temperatures in deeper water off the banks during all years show significant variations, but remained relatively warm with values in the 3°-6°C range, compared to much colder values (often <0°C) on St. Pierre Bank. Beginning around 1996 temperatures on St. Pierre Bank begin to moderate and by 2000 they reached the highest values since the late 1970s. During 2001-03 however, temperatures cooled significantly to values observed during the mid-1990s with the average temperature during the spring of 2003 the coldest in about 13 years. Temperatures during both 2004 and 2005 warmed considerably over 2003 values to 1°C above normal in some areas. On St. Pierre Bank bottom water with temperatures <0°C covered <10% of the total area during the warm years of 1999, 2000, 2004 and 2005. During the spring of 2007 however, near-bottom temperatures decreased to below normal values in many areas particularly on St. Pierre Bank, where the area of <0°C water increased to more than 50% of the total area. The most evident trend in the numbers of cod caught per set during the multi-species surveys was the high number of zero catches in the <0°C water on St. Pierre Bank and regions to the east of the Bank, mainly from 1985 to 1998 but also from 2001 to 2003. During 1999 and 2000 larger catches became more wide spread over St. Pierre Bank as cold (<0°C) water disappeared from the area. In general, cod tend to prefer the warmer (2°-6°C) portion of the available habitat with a slightly warmer preference based on weight than on total numbers. Finally, variations in the estimated abundance and biomass of cod from the RV surveys in strata with water depths generally <100 m are significantly correlated with bottom temperatures, indicating a potential climate effect on cod distribution in this area.

RÉSUMÉ

Nous examinons les données océanographiques obtenues dans la division 3P de l'OPANO au printemps 2007 et les comparons à celles de l'année précédente et aux moyennes à long terme (de 1971 à 2000). Les données montrent des périodes anormalement froides au milieu des années 1970 et du milieu des années 1980 jusqu'au milieu des années 1990, les températures se situant à 1 °C sous la moyenne et jusqu'à 2 °C sous les valeurs élevées de la fin des années 1970 et du début des années 1980. Les températures des eaux profondes au large des banc au cours de toutes les années varient énormément, mais sont demeurées relativement élevées, se maintenant dans une plage de 3 à 6 °C, comparativement aux températures bien plus froides (souvent < 0 °C) du banc de Saint-Pierre. Les températures ont commencé à se réchauffer autour de 1996 sur le banc de Saint-Pierre et, en 2000, elles ont atteint les valeurs les plus élevées depuis la fin des années 1970. Toutefois, entre 2001 et 2003, elles se sont considérablement refroidies, revenant aux valeurs observées au milieu des années 1990. La température moyenne dans la division 3P au printemps 2003 était la plus froide depuis environ 13 ans. Les températures en 2004 et en 2005 ont été considérablement plus chaudes que celles de 2003, atteignant 1 °C au dessus de la normale dans certaines zones. Sur le banc de Saint Pierre, l'eau de fond d'une température inférieure à 0 °C couvrait < 10 % de la superficie totale durant les années chaudes de 1999, 2000, 2004 et 2005. Au printemps 2007, toutefois, les températures près du fond ont baissé sous les valeurs normales à bien des endroits, notamment sur le banc de Saint-Pierre, où l'étendue des eaux dont la température était < 0 °C a augmenté, dépassant 50 % de la superficie totale. La tendance la plus évidente au plan de la quantité de morues capturées par mouillage d'engin lors des relevés plurispécifiques est le grand nombre de mouillages sans capture dans les eaux de température inférieure à 0 °C sur le banc de Saint-Pierre et dans les régions à l'est du banc, surtout de 1985 à 1998, mais aussi de 2001 à 2003. En 1999 et en 2000, les captures nombreuses sont devenues plus répandues sur le banc de Saint-Pierre à mesure que l'eau froide (< 0 °C) disparaissait de la région. De façon générale, les morues privilégient la portion de l'habitat disponible où les températures sont le plus élevées (entre 2 et 6 °C), la relation étant légèrement plus forte pour le poids des prises que pour leur nombre. Enfin, les variations d'abondance et de biomasse de la morue dans les strates de moins de 100 m de profondeur, estimées lors des relevés du navire de recherche, affichent une corrélation significative avec les températures de fond, indiquant un effet climatique possible sur la répartition de la morue dans ces zones.

INTRODUCTION

The general circulation in the 3P region consists of modified Labrador Current Water, the inshore branch of which flows through the Avalon Channel, and around Cape Race. This branch then divides into two parts, one flowing to the west around the north of St. Pierre Bank, and the other flows to the south between Green Bank and Whale Bank. Additionally, part of the offshore branch of the Labrador Current flows around the tail of the Grand Bank, westward along the continental slope (where it may interact with the Gulf Stream and slope waters), to the Laurentian Channel and into the Gulf of St. Lawrence (Fig. 1).

Since the early 1970s, the ocean environment in the Northwest Atlantic has been dominated by near-decadal oscillations with cold periods in the early 1970s, mid-1980s and early 1990s and a general warming trend towards the mid-to-late 1990s. During the cold periods, colder-than-normal winter air temperatures prevailed over the Northwest Atlantic resulting in increased winter and spring ice cover and a colder and fresher-than-normal water mass overlying most of the continental shelf in Atlantic Canada (Colbourne et al. 1994; Drinkwater 1996). These conditions generally correspond to periods of positive winter North Atlantic Oscillation (NAO) index anomalies. The extent to which events influences the 3P region are documented by several studies (Hutchings and Myers 1994; Moguedet and Mahe 1991; Battaglia and Poulard 1987; Forest and Poulard 1981; Colbourne 1994, 1996, 1999, 2000, 2001, 2002, and 2003, Colbourne and Murphy 2002, 2003 and 2004, 2005).

This report summarizes oceanographic conditions in NAFO Div. 3P up to the spring of 2007 in relation to the long-term mean and represents the 10th such review of winter/spring oceanographic conditions in support of the annual Atlantic cod assessments in this region. The base period used to compute anomalies is defined as the 30-year time period from 1971 to 2000. There are however, insufficient salinity data available in this time period to produce meaningful averages. Therefore the base period for salinity anomalies encompassed all available data from the mid-1920s to 2000.

Assessments of the cod stock in this region have indicated a steady decline in biomass (SPA estimates) from the peak in 1985 to a minimum in 1992 followed by an increase during 1993-97 after the implementation of a fishing moratorium. Recruitment also experienced a general decline since the early 1980s remaining at historical low values during most of the 1990s with a slight increase during 1997-99 (Brattey et al. 2002). In this report, we present an overview of oceanographic conditions during 2005 and 2007 and provide an update to Colbourne and Murphy (2005), where a review of recent trends in the distribution and abundance of cod in relation to their thermal habitat was presented. Insufficient survey coverage in 2006 prevented a similar analysis.

DATA AND METHODS

Oceanographic data for NAFO Div. 3P are available from archives at the Marine Environmental Data Service (MEDS) in Ottawa and from a working database maintained at the Northwest Atlantic Fisheries Centre (NAFC) in St. John's NL. The bulk of these data are temperature profiles collected during the Canadian groundfish assessment surveys of February, March and April since 1973. The station positions where oceanographic measurements were available from the 2007 multi-species survey are shown in Fig. 1. Since the winter of 1990, water temperatures and salinity on these surveys have been measured, for the most part, using a trawl-

mounted Seabird 19 CTD. Prior to that, XBTs were the primary instrument. Data from the net-mounted CTDs are not field calibrated, but are checked periodically and factory calibrated when necessary maintaining an accuracy of 0.005°C in temperature and 0.005 in salinity. The XBTs are accurate to within 0.1°C. In addition to these data, all available historical data in the period 1971-2000 were used to establish the long-term means.

Vertical cross-sections of the temperature and salinity fields and their anomalies for April 2005 and 2007 were constructed by projecting the positions of all observations in corridor A (Fig. 1 bottom panel) along a straight line with their offshore distances calculated from the shoreline in Sub-division 3Pn. The cross-section begins near Rose Blanche on the south coast of Newfoundland, and then follows a southeasterly direction crossing Burgeo Bank, Hermitage Channel, and St. Pierre Bank, terminating near the edge of the continental shelf on the southwestern Grand Bank.

All available oceanographic data were gridded for the winter-spring period of each year at a spatial resolution of approximately 100 km^2 or approximately 0.1° latitude by 0.1° longitude. The mean bottom temperature for each grid element was calculated and combined with the grid area to produce a time series of the spatially averaged bottom temperature and the total bottom area covered by water in selected temperature ranges. Bottom temperature maps and their anomalies were constructed by contouring the near bottom temperature values, rejecting ones for which the cast depths were not within 10% of the actual water depth. Some temporal biasing may exist in the T/S fields represented by these maps, particularly in shallow regions, given the large area and wide time interval (up to one month) over which the data were collected.

Annual surface, bottom and vertically averaged temperature anomalies were constructed from all available data throughout the year corresponding to area B on St. Pierre Bank (Fig. 1 bottom panel). The 1971-2000 data set from this area was sorted by month to determine monthly means. The seasonal cycle was then removed from each observation by subtracting the monthly mean to determine anomalies. Unlike the time series of anomalies from fixed points (e.g. Station 27); these anomalies are based on data collected over larger geographical areas and therefore may exhibit variability due to spatial differences in the monthly estimates. In addition, the annual values may be based on only a few monthly estimates for the year, mainly spring in this region. Therefore, caution should be used when interpreting short time scale features of these series. The long-term trends however, generally show real features.

The number of cod of all ages per set is displayed as expanding symbols together with the temperature contours for selected surveys, with an update for 2007. The survey catch data from 1983 to the spring of 1995, which were collected using an Engel 145 bottom trawl, were converted to equivalent Campelen trawl units based on the results of comparative fishing studies. Inter-annual variations in the thermal habitat and its effects on cod are then considered by examining the mean temperature fields in relation to the RV estimates of biomass and abundance.

PHYSICAL OCEANOGRAPHY
TEMPERATURE AND SALINITY SECTION

Vertical cross-sections of the temperature and salinity and their anomalies for April of 2005 and 2007 based on the multi-species survey data within Box A (Fig. 1) are displayed Fig. 2. No attempts were made to adjust this average for possible temporal or spatial biasing arising from variations either in the number of observations within the time interval or within the area.

The average upper layer temperature during April from near shore at Rose Blanche on the south coast of Newfoundland over Burgeo Bank and Hermitage Channel is about 1°C. On St. Pierre Bank temperatures generally range from 1°C near the bottom to 2°C near the surface and from 1°-2°C beyond the shelf edge in the upper 100-m of the water column. In the deeper water of Burgeo and Hermitage Channels and on the continental slope temperatures are highly variable and generally range from 2°C at approximately 125-150 m depth to 5°-7°C below 150 m depth. At the edge of the continental shelf on southeastern St. Pierre Bank, the temperature field is marked by a strong gradient separating the warmer slope water from Newfoundland Shelf Water that is advected into the region by the inshore branch of the Labrador Current. In this region water temperature increases from about 1°C at about 100 m depth, to between 5°-6°C at about 175 m depth, an average vertical temperature gradient of 1°C per 15 m depth change (Colbourne 2000).

Upper layer salinity during April inshore at Rose Blanche and over Burgeo Bank and Hermitage Channel generally range from about 32 to 32.2. On St. Pierre Bank, salinities generally range from 32.5 near bottom, to a minimum of 32.1 in the near-surface waters. Along the shelf edge, in the upper 100-m of the water column a strong density front separates the saltier slope water from the fresher shelf water on St. Pierre Bank, in this region salinities increase from 32.3 to over 34. In the deeper waters of Burgeo and Hermitage Channels and on the continental slope regions salinities normally increase from 33 at approximately 130 m to 34.5 near bottom (Colbourne 2000).

During April 2005, upper layer temperatures along the section increased over 2004 values and were over 2°C in many areas. Temperature anomalies range from 0.5-1.0°C above normal over St. Pierre and Burgeo Banks. In the deeper waters (>135 m) of Burgeo and Hermitage Channels and in the extreme southeastern areas temperatures were below normal (Fig. 2a top panels). In general however, spring temperatures along this section over most of the water column during 2005 were above normal, reversing the cold conditions observed during 2003. In 2007 water column temperatures decreased significantly over 2005 values and were mostly in the range of 0.5°-1°C in the upper 100 m. Below 100 m depth temperatures were warmer, increasing to a maximum of 7°-8°C in Hermitage Channel. Except for these values and a small area near-bottom on the southeast St. Pierre Bank, temperatures along the section were below the long-term mean.

During April of 2005 (Fig. 2b upper panels) near-surface salinities were <32.5 which was near the long-term mean. Salinities below 100-m depth increased from 32.5 to >34.5 near bottom, which again were near-normal. Upper layer salinities along the section during April 2007 increased since 2005 with values mostly in the range of 32.5-33.0 which is generally above the long-term mean.

BOTTOM TEMPERATURES

Average bottom temperature during April ranged from 5°C in the Laurentian, Burgeo and Hermitage Channels to about 3°-4°C on Rose Blanche and Burgeo Banks. On St. Pierre Bank bottom temperatures range from 0°C on the eastern side to 2°-3°C on the western side. In general, bottom isotherms follow the bathymetry along the Laurentian Channel and the southwestern Grand Bank, increasing from 2°C at 200 m depth to about 5°C below approximately 300 m depth (Colbourne 2000).

During the spring of 2003, bottom temperatures over St. Pierre Bank decreased significantly over the previous year with <0°C water covering most of the Bank and regions to the east (Colbourne and Murphy 2003). During the spring of 2004 and 2005 bottom temperatures increased significantly with <0°C water restricted to the approaches to the Placentia Bay area. As a result bottom temperatures were up to 1°C above normal in many areas. In 2007, spring bottom temperatures again decreased with below normal values covering most areas, similar to 2003 conditions.

Annual values of the areal extent of the bottom covered with water in the temperature ranges of <0°C, 0°-1°C, 1°-2°C, 2°-3°C and >3°C are displayed in Fig. 4. Note the large increase in the percentage area of the bottom covered by <0°C water in 1985 that persisted well into the mid-1990s, with the exception of 1988. The percentage area covered by <0°C water during the spring of 1998 decreased to pre-1985 levels and to less than 10% during 2000, but increased to over 25% during 2001 and 2002 and to near 40% in 2003. This area decreased to <10% during the spring of 2004 and 2005 but increased to >25% in 2007. The area of the bottom covered with water >3°C was between 60-70% prior to the 1980s but since then is has remained relatively constant between 40-50%.

The spatially averaged bottom temperature (Fig. 4 bottom panel) in Division 3P ranged between 2°-4°C from 1970 to 1984 and decreased to between 2°-2.5°C from 1985 to 1997. From 1998 to 2007 the average near-bottom temperature varied between 2°-3°C. On the banks, in water depths generally <100 m, the average temperature from 1970 to 1985 ranged between approximately 0.5°-1°C. It then decreased significantly during 1985 and slowly recovered to about 1.7°C by 2000. During 2001 to 2003, bottom temperature on the banks decreased to -0.7°C the lowest since 1985, increased to 1°C by 2005 but decreased to 0°C during the spring of 2007. No data were available for 2006.

LONG-TERM TRENDS

Annual estimates of near-surface, 75 m depth and the 0-50 m vertically averaged temperature anomalies from 1950 to 2007 on St. Pierre Bank bounded by Area B in Fig. 1b are displayed in Fig. 5. The time series is characterized by large inter-annual variations with amplitudes ranging from ±1.5°C from normal. The long-term trend shows amplitudes generally less than ±1°C with periods between 5-10 years. The cold periods of the mid-1970s and the mid-1980s in the upper water column are coincident with severe meteorological and sea-ice conditions in the Northwest Atlantic and generally colder and fresher than normal waters over most of the Canadian Continental Shelf. During the cold period beginning around 1984 temperatures decreased significantly by over 1°C in some years. This below normal trend continued until the mid-1990s, since then however temperatures began to warm reaching near-record values in 2005 and 2006 before falling to below normal again in 2007. It should be noted that these anomalies are

based on data collected over relatively large geographical areas; in addition the annual estimates may be based on a few monthly estimates for the year. Caution therefore should be used when interpreting short time scale features of these series. The long-term trends however, generally show real features.

ATLANTIC COD AND THE PHYSICAL ENVIRONMENT

The near-bottom habitat in the 3P region consists of two distinct oceanographic regimes. The one influenced by cold and relatively fresh water advected from the eastern Newfoundland Shelf by the inshore branch of the Labrador Current, accounting for about 40% of the total area, includes much of St. Pierre Bank and regions to the east. In this area temperatures generally range from 0°-2°C but are often <0°C in many years. The other regime includes the deeper portions of the Laurentian and Hermitage Channels and areas to the west of St. Pierre Bank. This area appears to be influenced mostly by warmer slope water from the south. Consequently, this region experiences high variability with temperatures ranging from 3°-6°C. A change in the thermal habitat influenced by the Labrador Current took place during the mid-1980s with a significant increase in the area of the bottom covered with <0°C water. Beginning in 1996 the area of <0°C water on the banks decreased significantly, reaching very low values in 1998 and essentially disappearance during the warm years of 1999 and 2000 and again in 2004 and 2005.

Spring bottom temperature maps together with the number of fish caught per set for Div. 3P are shown in Fig. 6 for 1993 a cold year, 2000 a warm year and for 2005 and 2007. A complete set of cod catches and temperature maps for the years 1983 to 2007 are displayed in Appendix 1. Note the low number of cod caught per set (displayed as expanding symbols on the temperature fields) during the cold year of 1993. This pattern persisted during most years from 1985 to 1998 when most of St. Pierre Bank and regions east of the Bank were covered by bottom water with temperatures <0°C. During 1999 and 2000 (Fig. 6) larger catches became more wide spread over St. Pierre Bank and surrounding area as cold (<0°C) water disappeared from the area (Colbourne and Murphy 2002). During 2001 to 2003 however, cold water returned to the area and the number of fishing sets with zero catches also increased. During all surveys including the current year most of the larger catches occurred in the warmer (2°-4°C) waters along the slopes of the banks and in the deep channels to the west of St. Pierre Bank.

To investigate possible temperature preferences by cod in this region, cumulative distributions of temperature and catch weighted (in terms of numbers and weight) cumulative distribution of temperature for various periods are displayed in Fig. 7. The temperature distributions have been weighted annually by sampling intensity within each stratum and by strata area. The cumulative frequency distribution of temperature shows the temperature available to cod historically during the spring period in Division 3P. The cod number and weight temperature distributions show the distribution of catches in relation to the ambient temperature. The results indicate that on average (1972-2001) cod are associated with the warmer portion of the available temperature range with a slightly warmer preference based on weight than numbers. This may imply a greater degree of habitat selection by larger mature cod. Approximately 20% of the cod by number are associated with <0°C water, while approximately 50% are associated with water >3°C and up to 25% associated with temperatures >5°C. The temperature distribution indicate that about 40% of the surveyed habitat is normally (1972-2001) covered by water with temperatures <0°C. During the warm periods of 1998-2000 the distribution of catches nearly coincided with the distribution of available temperature, but during cold periods of 1985-1995 and 2001-2003, the distributions indicate that the fish may avoid the colder portions of the habitat (Fig. 7). The distributions during 2005 are similar to those observed during other warm periods however some of the variability is due to two large sets

containing over 50% of the total number of fish caught in 0.8 and $1.3^{\circ}C$ bottom water. During the 2007 survey it appears that cod were found in all available temperatures, although in very low numbers on St. Pierre Bank.

Inter-annual variations in the spatially averaged bottom temperature of the surveyed area in Div. 3P are plotted in Figs. 8 and 9 together with the RV estimates of abundance and biomass for the years 1983 to 2007. Apart from the general decrease in both abundance and bottom temperature from the mid-1980s to the early 1990s and for the most recent years, there is no significant correlation between bottom temperatures and the abundance and biomass of cod (Fig. 8). On the banks however, and in water depths <100 m, the average bottom temperature is significantly correlated with the RV abundance ($r=0.61$, $p<0.05$) and biomass ($r=0.64$, $p<0.05$) corresponding to strata with water depths <92 m (Fig. 9). In general, the cold bottom temperatures experienced during the winter and spring from the mid-1980s to the mid-1990s and during 2001 to 2003 correspond to low RV estimates of abundance and biomass for these strata.

The results presented suggest that cod tend to avoid the colder portions of the thermal habitat in this region and consequently change their spring distribution from one year to the next, depending on ocean climate conditions. This result is not without exception however (e.g. 1983, 1987 and 2004) and there may be other reasons for the observed changes in distribution. For example, the extreme variations in the catch rates on St. Pierre Bank, in particular, may be the result of a temperature dependent increase in catchability. It could also be related to other biological or environmental factors, such as increase in prey species or a shift to a more suitable environment for prey species. Variations in the catch rates in the warmer water of the most western regions of Subdiv. 3Pn may be influenced by environmental conditions in the Gulf of St. Lawrence, either for cod or their prey, or both. Although the numbers of fish from the 1983-1995 surveys have been converted to equivalent Campelen trawl units there may be some residual effects remaining in the series, which may have contributed to some of the increase in the catches of smaller fish during 1996-2007. Variations in water temperature in the area, particularly on St. Pierre Bank and the eastern areas of 3P may also influence spawning success and possibly improved survival and growth rates of cod.

SUMMARY

Time series of temperature anomalies from NAFO Division 3P (particularly on St. Pierre Bank) show anomalous cold periods in the mid-1970s and from the mid-1980s to late 1990s. These conditions were similar to those observed along the east coast of Newfoundland and Labrador, except the latter cold period lasted longer on St. Pierre Bank than it did on the eastern Newfoundland Shelf. During the most recent cold period, which started around 1985, temperatures were up to $1^{\circ}C$ below average over all depths and up to $2^{\circ}C$ below the warmer temperatures of the late 1970s and early 1980s in the surface layers. Temperatures in deeper water off the banks during all years show significant variations, but remained relatively warm with values in the 3°-$6^{\circ}C$ range, compared to much colder values (often $<0^{\circ}C$) on St. Pierre Bank. Beginning around 1996 temperatures on St. Pierre Bank started to moderate, decreased again during the spring of 1997, but returned to normal values during 1998. During 1999 and 2000 temperatures continued to increase reaching the highest values since the late 1970s in the surface layers. During the spring of 2001-03 however, temperatures cooled significantly over the previous two years to values observed during the mid-1980s by the spring of 2003. Temperatures during the spring of 2004-06 warmed considerably over 2003 values to $>1^{\circ}C$ above normal at the surface and near bottom and $>0.5^{\circ}C$ over the upper 50 m of the water column. In the spring of 2007 however temperatures once again decreased to below normal values in most areas of Div. 3P.

The areal extent of bottom water with temperatures <0°C increased significantly from the mid-1980s to the mid-1990s. During 1998-2000 this area decreased to very low values but increased again in 2001-03, returning to values observed during the mid-1990s and to the highest in about 13 years during 2003. During the spring 2004 and 2005 this area decreased to <10%, the lowest since 1988 but increased to >25% in 2007. The areal extent of bottom water with temperatures >3°C has remained relatively constant at about 50% of the 3P area during the past decade. On St. Pierre Bank bottom water with temperatures <0°C covered <10% of the total area during the warm years of 1999 and 2000. It reappeared again however during 2001-03 reaching about 90% of the area of the Bank in 2003. After 3 years (2004-06) of relatively warm conditions on St. Pierre Bank cold <0°C water returned during the spring of 2007 to cover most of the bank.

The analysis presented here show significant variations in the water mass characteristics particularly on St. Pierre Bank during the past three decades. The dominant oceanographic signal potentially influencing cod habitat in the region is the volume of <0°C water advected into the area from the eastern Newfoundland Shelf by the inshore branch of the Labrador Current. The spatial extent and temperature of this water mass that eventually makes its way onto St. Pierre Bank is governed by advection rates, vertical mixing by storms during the winter and spring and surface heat flux. The most evident trend in the numbers of cod caught per set is the high number of zero catches in the cold (<0°C) waters on St. Pierre Bank and regions to the east of St. Pierre Bank mainly from 1985 to 1998 and from 2001 to 2004. During 1999 and 2000 larger catches became more wide spread over the St. Pierre Bank region as the cold (<0°C) water disappeared from the area. In general, during most surveys large catches of cod occurred in the warmer waters (2°-6°C) along the slopes and areas to the west of St. Pierre Bank.

In 2004 there was no observed shift in the distribution of cod over St. Pierre Bank and there were many low or zero catches in the warm deeper waters off the banks compared to most years but during 2005 catch rates increased somewhat in most areas including St. Pierre Bank. During 2007 cod were found in all available temperatures, although in very low numbers on St. Pierre Bank. Variations in the estimated abundance and biomass of cod in strata with water depths <92 m are significantly correlated with bottom temperatures for that depth range. However, there is no significant correlation between bottom temperatures and the abundance of cod for strata with water depths >100 m. Nevertheless, it appears that cod tend to avoid the colder portions of the thermal habitat in most years and consequently change their spring distribution from one year to the next, depending on ocean climate conditions.

ACKNOWLEDGMENTS

We thank C. Fitzpatrick, D. Senciall, J. Craig, W. Bailey and P. Stead of the oceanography section at NAFC for data processing and computer software support. We also thank the many scientists and technicians at NAFC for collecting and providing the data from the multi-species surveys in NAFO Div. 3P and the national Integrated Data Management (ISDM) branch in Ottawa for providing the historical oceanographic data.

REFERENCES

Battaglia A. and Poulard J.C. 1987. Year to year variations in water temperature in NAFO Subdivision 3Ps. NAFO SCR Doc. 87/26, Ser. No. N1310, 16p.

Brattey, J., Cadigan N.G., Healey B.P., Lilly G.R., Murphy, E.F., Shelton, P.A., Stansbury, D.E. and Mahé J.-C. An assessment of the cod (*Gadus morhua*) stock in NAFO Subdiv. 3Ps in October 2002. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/096. 102 p.

Colbourne, E.B. and Murphy, E.F. 2005. Physical oceanographic conditions in NAFO Division 3P during 2005 - possible influences on the distribution and abundance of Atlantic cod *(Gadus morhua).* DFO Can. Sci. Advis. Sec. Res. Doc. 2005/065.

2004. Physical oceanographic conditions in NAFO Division 3P during 2004 - possible influences on the distribution and abundance of Atlantic cod *(Gadus morhua).* DFO Can. Sci. Advis. Sec. Res. Doc. 2004/086.

2003. Physical oceanographic conditions in NAFO Division 3P during 2003 - possible influences on the distribution and abundance of Atlantic cod (*Gadus morhua*) DFO Can. Sci. Advis. Sec. Res. Doc. 2003/093. 24p.

2002. Recent trends in bottom temperatures and distribution and abundance of cod (*Gadus morhua*) in NAFO Subdivisions 3Pn and 3Ps from the winter/spring multi-species surveys. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/001. 18p

Colbourne, E.B. 2003. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 2002 with comparisons to the long-term (1971-2000) average. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/001 17p.

2002. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 2001 with comparisons to the long-term (1971-2000) average. DFO Can. Sci. Advis. Sec. Res. Doc. 2002/024 19p.

2001. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 2000 with comparisons to the long-term (1961-1990) Average. DFO Can. Sci. Advis. Sec. Res. Doc. 2001/005 18p.

2000. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 1999 with comparisons to the long-term (1961-1990) average. DFO Can. Sci. Advis. Sec. Res. Doc. 2000/049 20p.

1999. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 1997 and 1998 with comparisons to the long-term (1961-1990) average. DFO Can. Sci. Advis. Sec. Res. Doc. 1999/039 18p.

1996. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps during 1995 and 1996 with comparisons to the long-term (1961-1990) average. DFO Can. Sci. Advis. Sec. Res. Doc. 1996/094 14p.

1994. Oceanographic conditions in NAFO Subdivisions 3Pn and 3Ps, with Comparisons to the long-term average. DFO Atl. Fish. Res. Doc. 1994/026. 47p.

Colbourne, E.B., Narayanan, S. and Prinsenberg, S. 1994. Climate change and environmental conditions in the Northwest Atlantic during the period 1970-1993. ICES Mar. Sci. Symp. 198: 311-322.

Drinkwater, K.F. 1996. Atmospheric and oceanic variability in the northwest Atlantic during the 1980s and early 1990s. J. Northw. Atl. Fish. Sci. 18: 77-97.

Forest, A. and Poulard, F.C. 1981. Water temperature distributions on NAFO Subdivision 3Ps in autumn 1980 and late winter 1981. NAFO SCR Doc. 81/VI/45, Ser. No. N327, 9p.

Hutchings, J.A. and Myers, R.A. The timing of cod reproduction: Interannual variability and the influence of temperature. 1994, Mar. Ecol. Prog. Ser. 108: 21-31.

Moguedet Ph. and Mahe, J.-C. 1991. Yearly variations in water temperature in NAFO Subdivision 3Ps from 1978 to 1990. NAFO SCR Doc. 91/24, Ser. No. N1904, 9p.

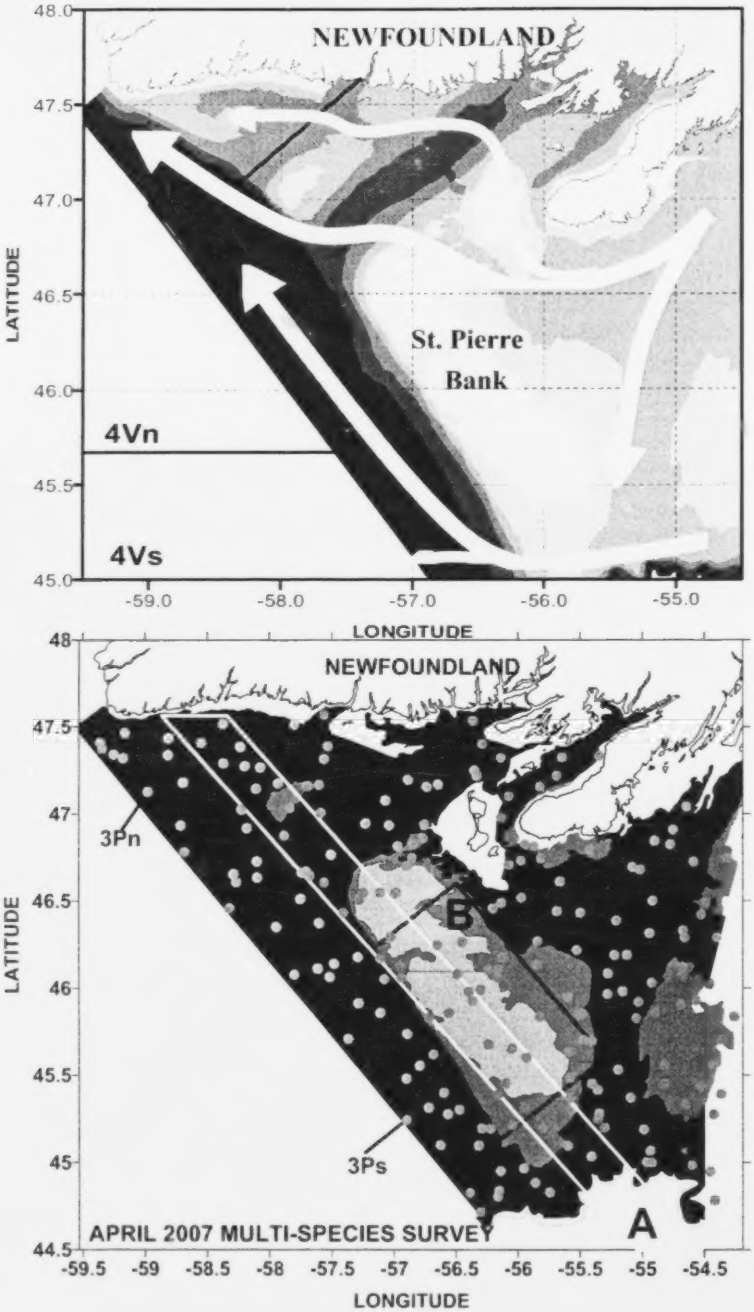


Figure 1a. Location maps showing bathymetric features, strata boundaries, the general ocean circulation, fishing set locations for the spring 2007 multi-species survey and areas A and B from which cross-sections and time series of temperature and salinity were constructed in NAFO Division 3P.

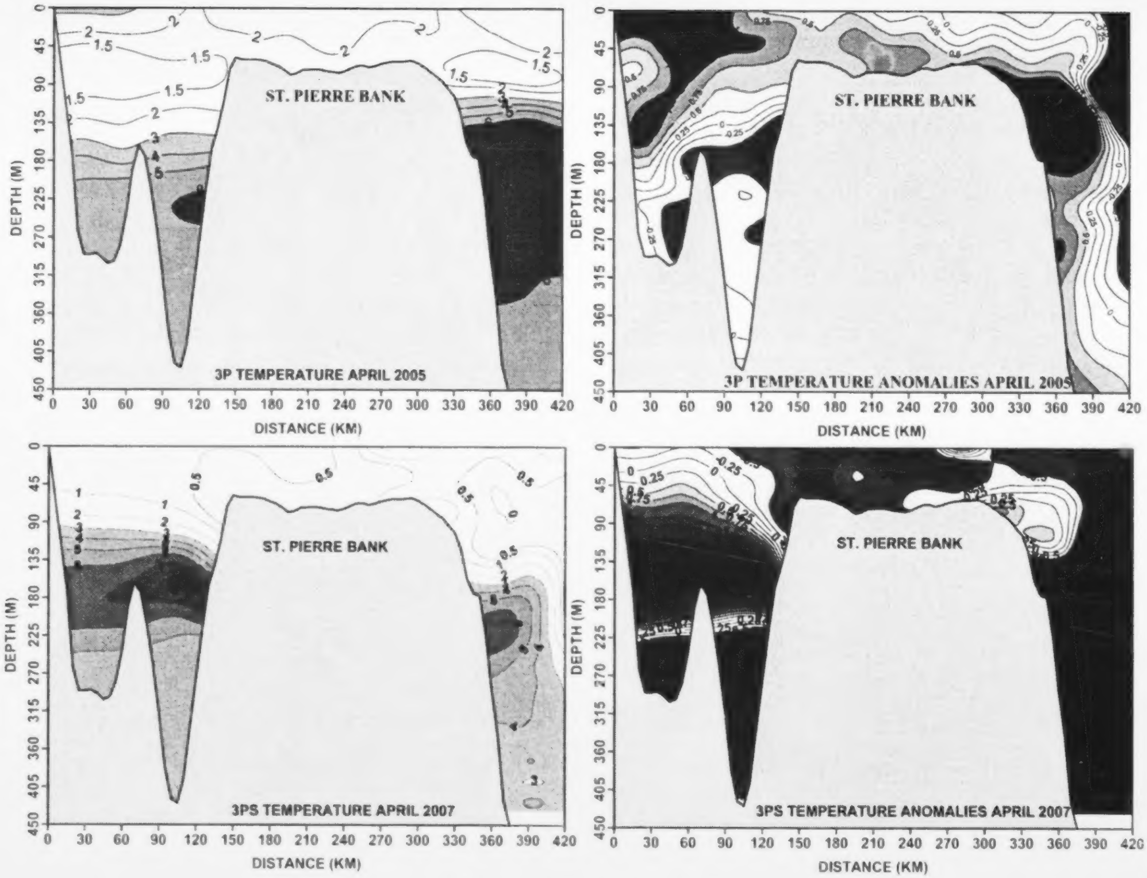


Figure 2a. The April 2005 and 2007 temperature and anomalies (in °C) along the section constructed from the data in Box A of Fig. 1b for NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1971-2000 average.

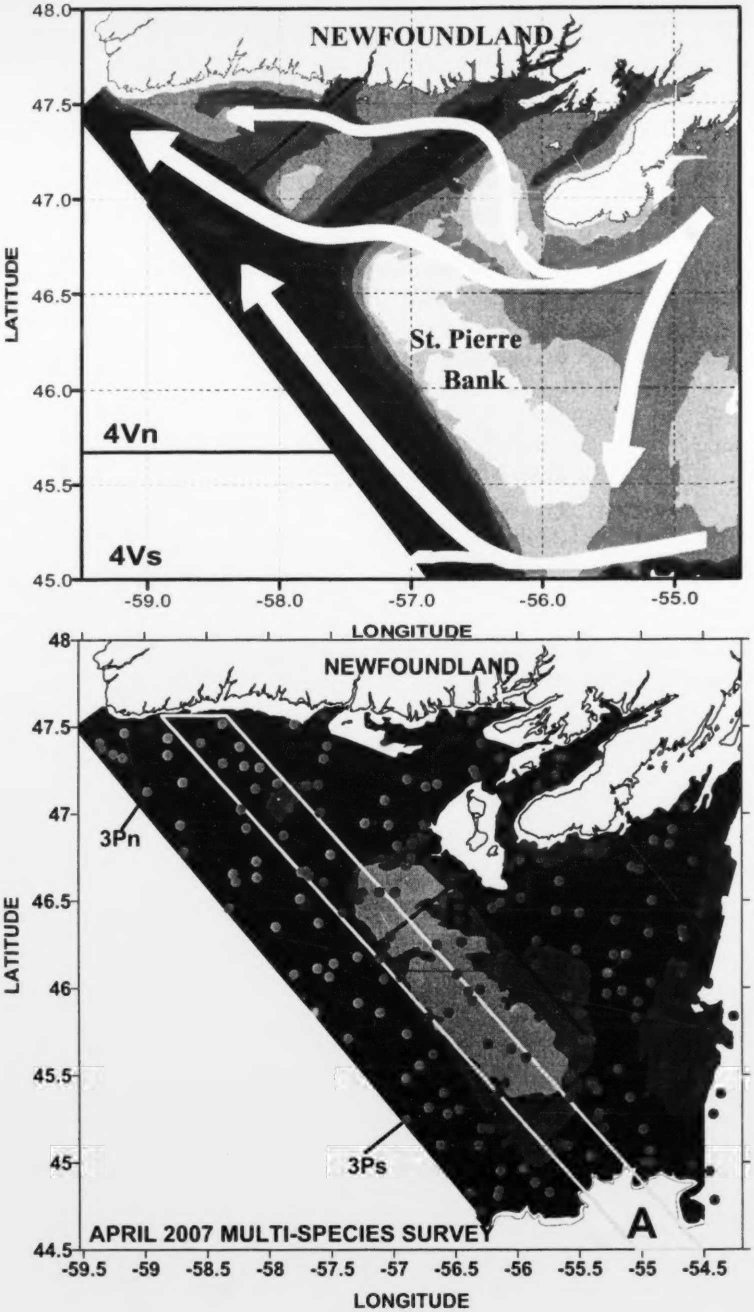


Figure 1a. Location maps showing bathymetric features, strata boundaries, the general ocean circulation, fishing set locations for the spring 2007 multi-species survey and areas A and B from which cross-sections and time series of temperature and salinity were constr_cted in NAFO Division 3P.

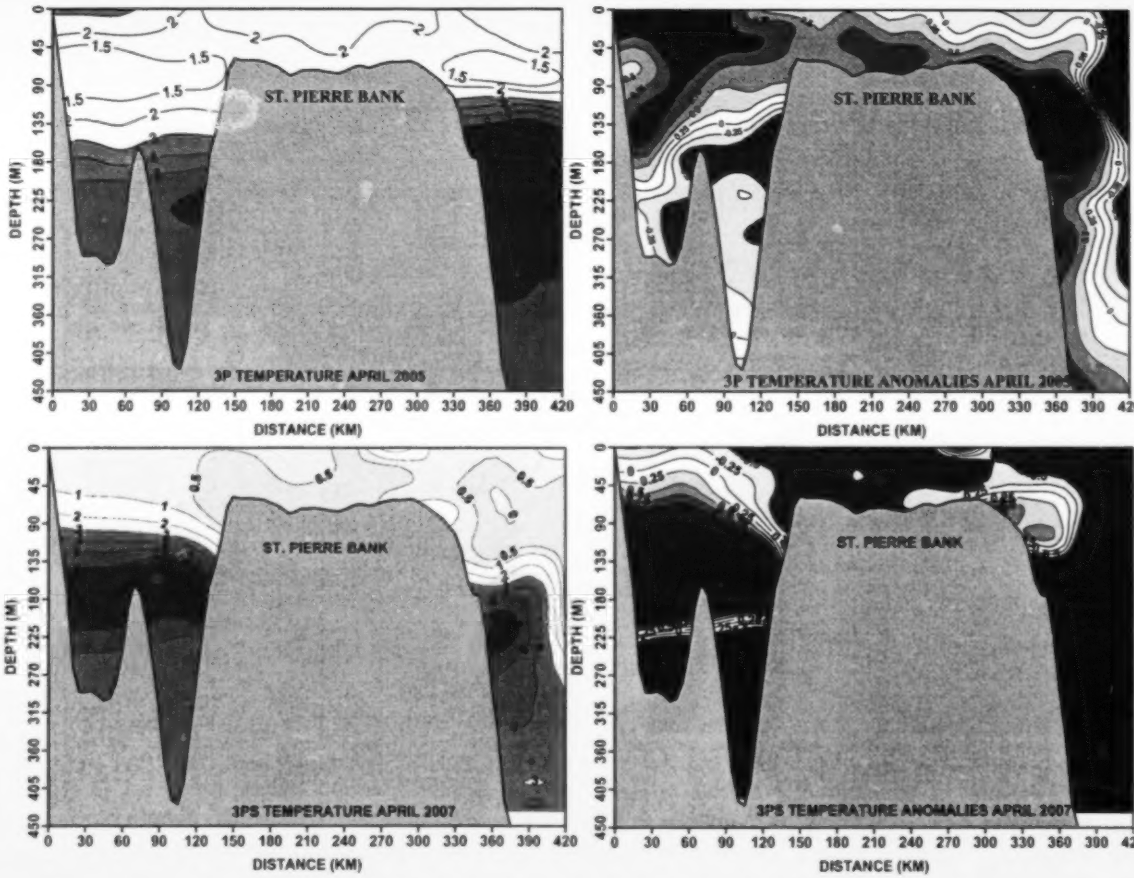


Figure 2a. The April 2005 and 2007 temperature and anomalies (in °C) along the section constructed from the data in Box A of Fig. 1b for NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1971-2000 average.

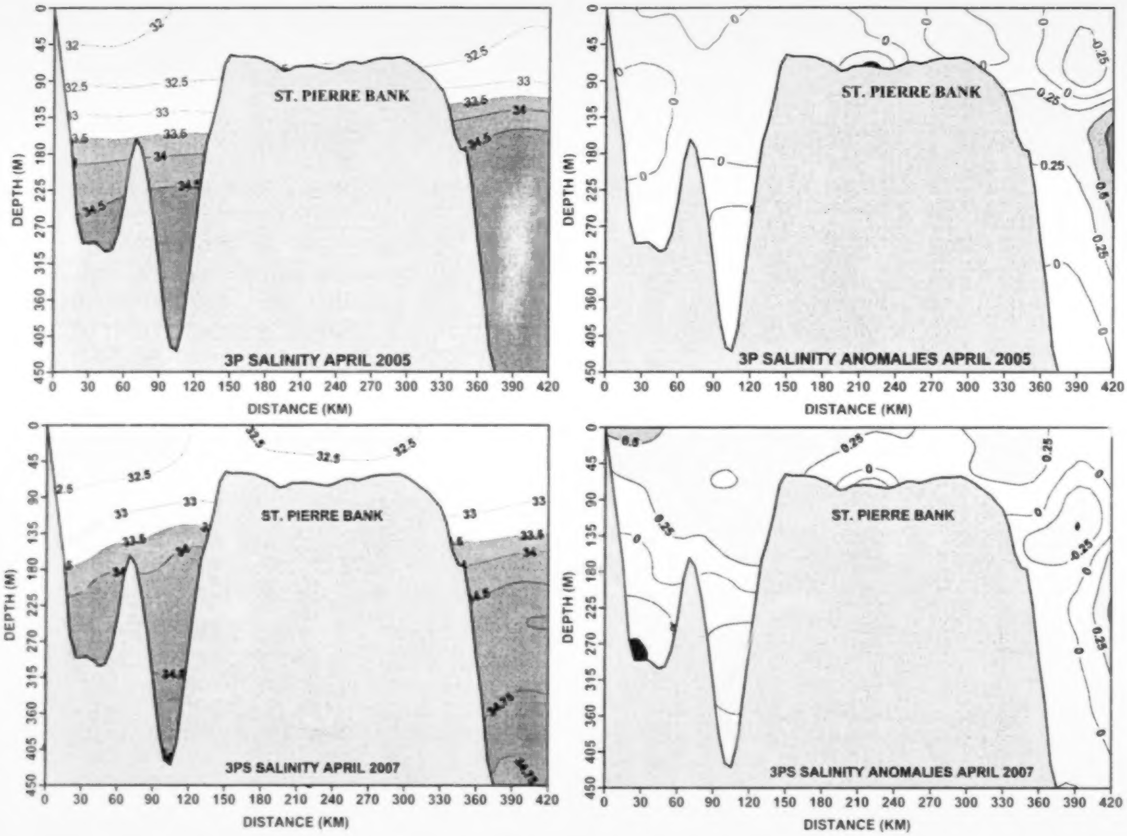


Figure 2b. The April 2005 and 2007 salinity and salinity anomalies along the section constructed from the data in Box A of Fig. 1b for NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1925 to 2000 average.

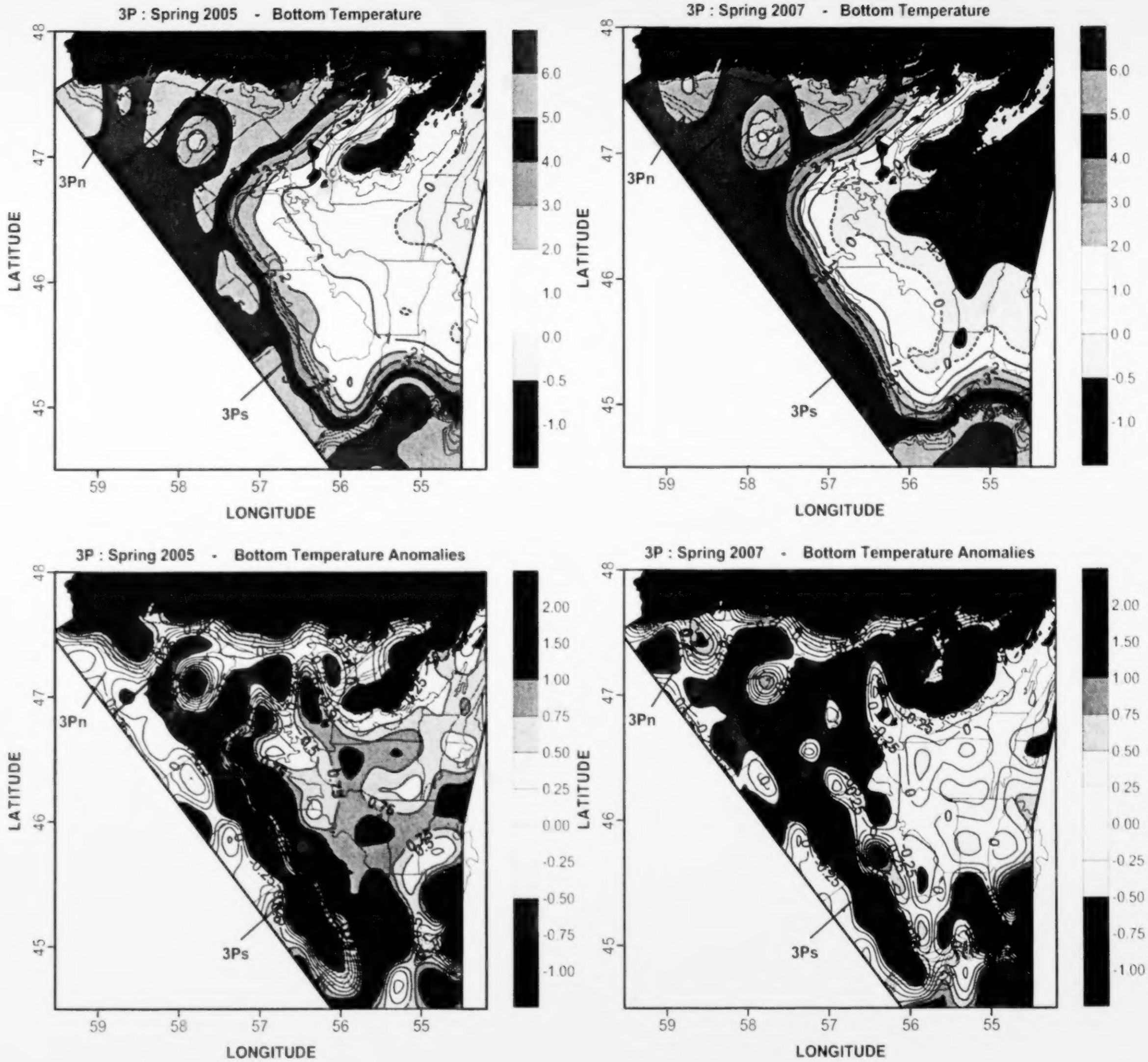


Figure 3. The April 2005 and 2007 bottom temperature and anomalies (in °C) in NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1971-2000 average.

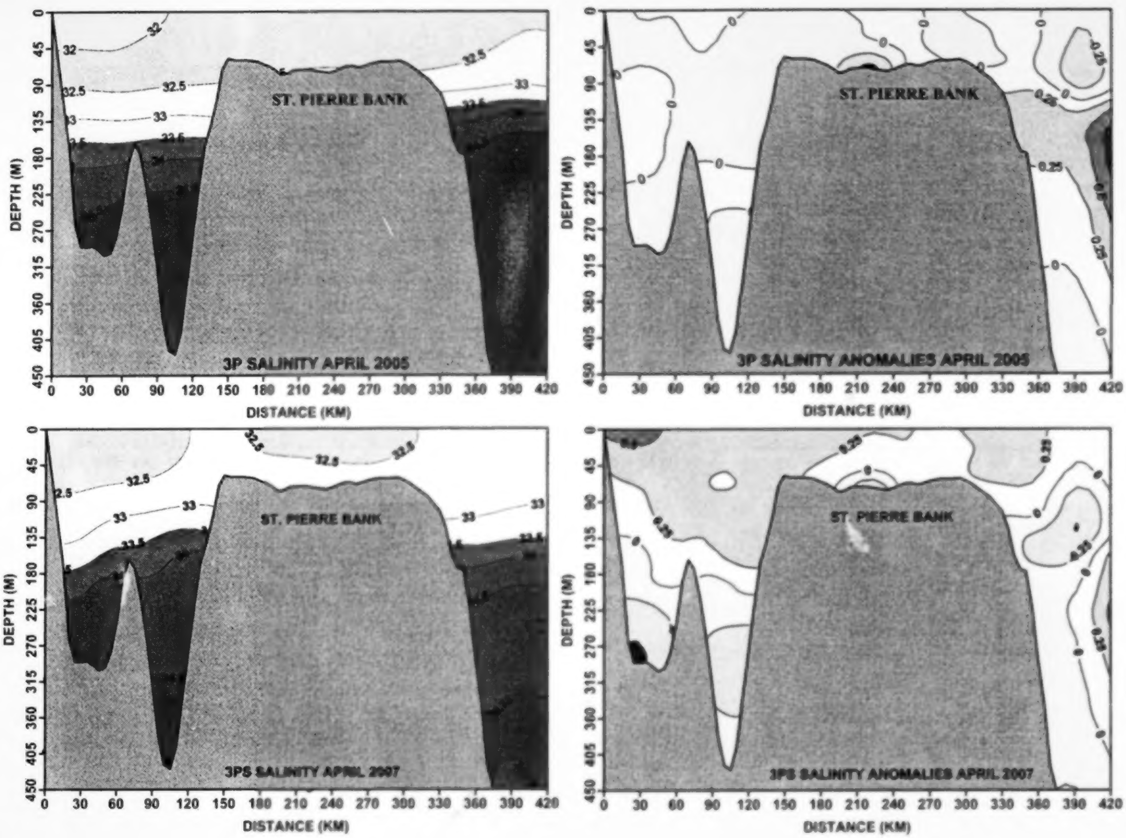


Figure 2b. The April 2005 and 2007 salinity and salinity anomalies along the section constructed from the data in Box A of Fig. 1b for NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1925 to 2000 average.

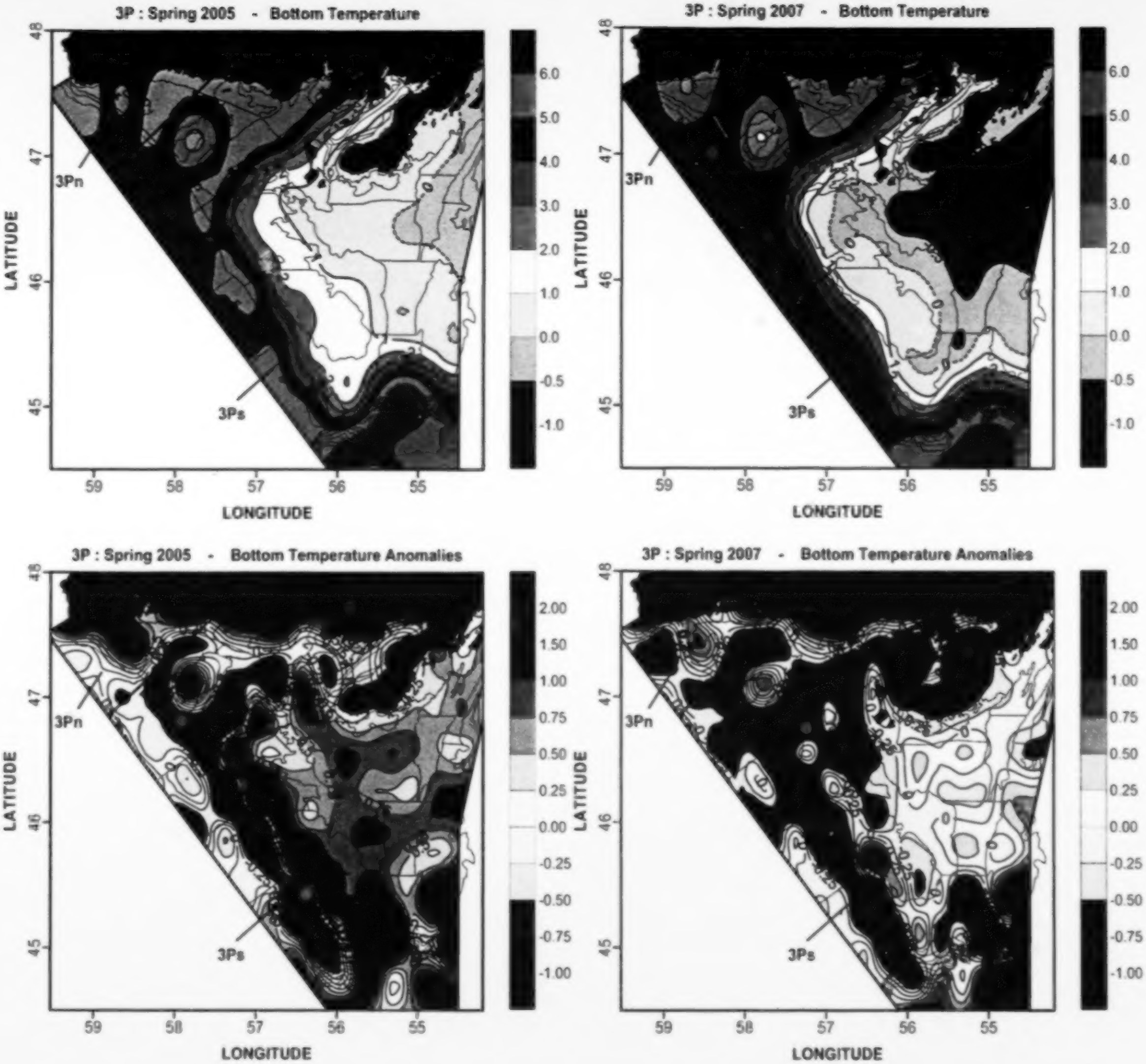


Figure 3. The April 2005 and 2007 bottom temperature and anomalies (in °C) in NAFO Subdivisions 3Pn and 3Ps. The anomalies are referenced to the 1971-2000 average.

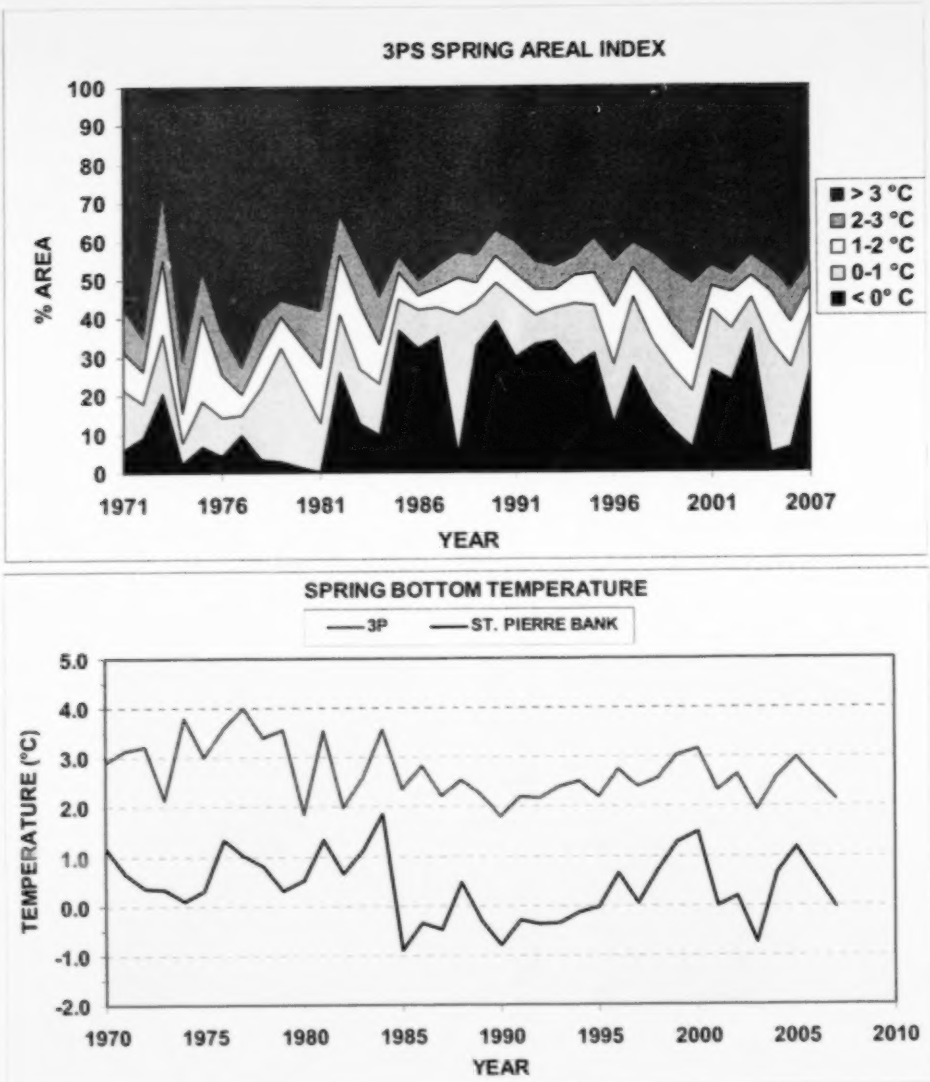


Figure 4. Time series of the percentage area of the bottom in NAFO Division 3P during the winter/spring covered by water with temperatures ≤0°C, 0°-1°C, 1°-2°C, 2°-3°C and ≥3°C (top panel) and the mean bottom temperature (in °C) for all strata and for strata with water depths <100 m (bottom panel).

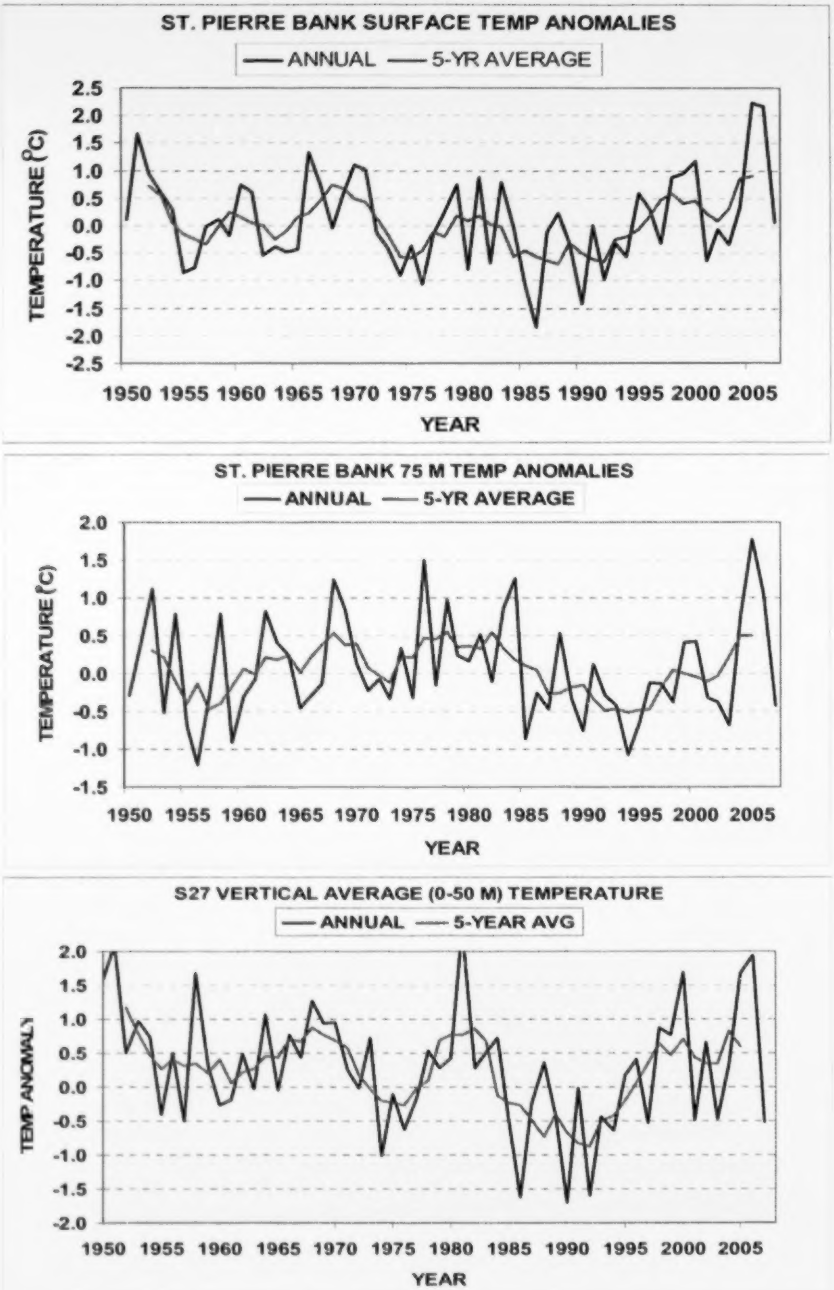


Figure 5. Annual temperature anomaly time series (in °C) for the near-surface (5 m) and near-bottom (75 m) and the vertically (0-50 m) average constructed from all historical data in Box B of Fig. 1b. The heavy solid line represents the 5-year running mean.

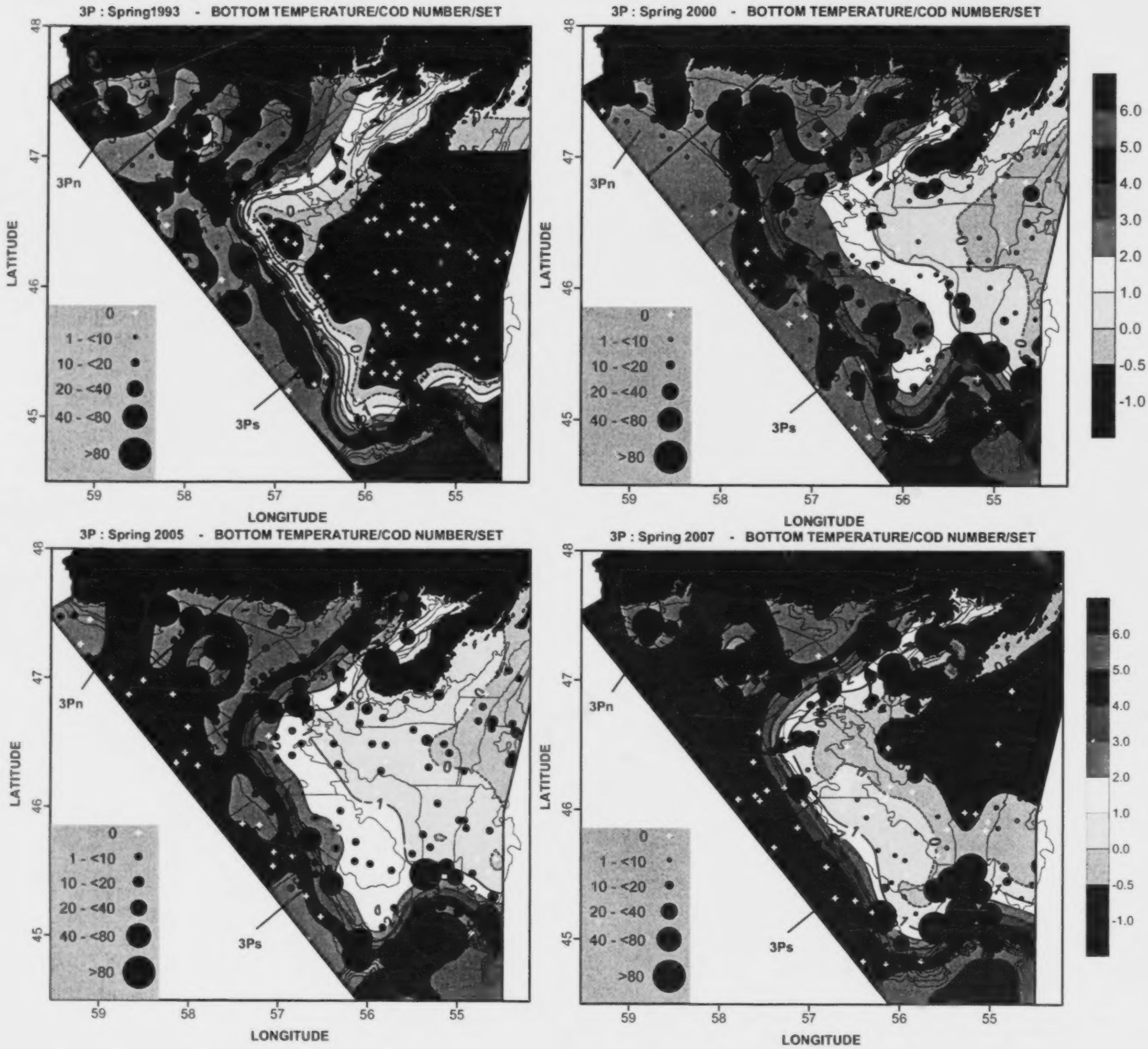


Figure 6. Bottom temperature contour maps (in °C) for 1993, 2000, 2005 and 2007 based on data collected during the spring multi-species survey of Division 3P. The numbers of cod in each fishing set are shown as solid expanding circles. The white crosses represent zero catches.

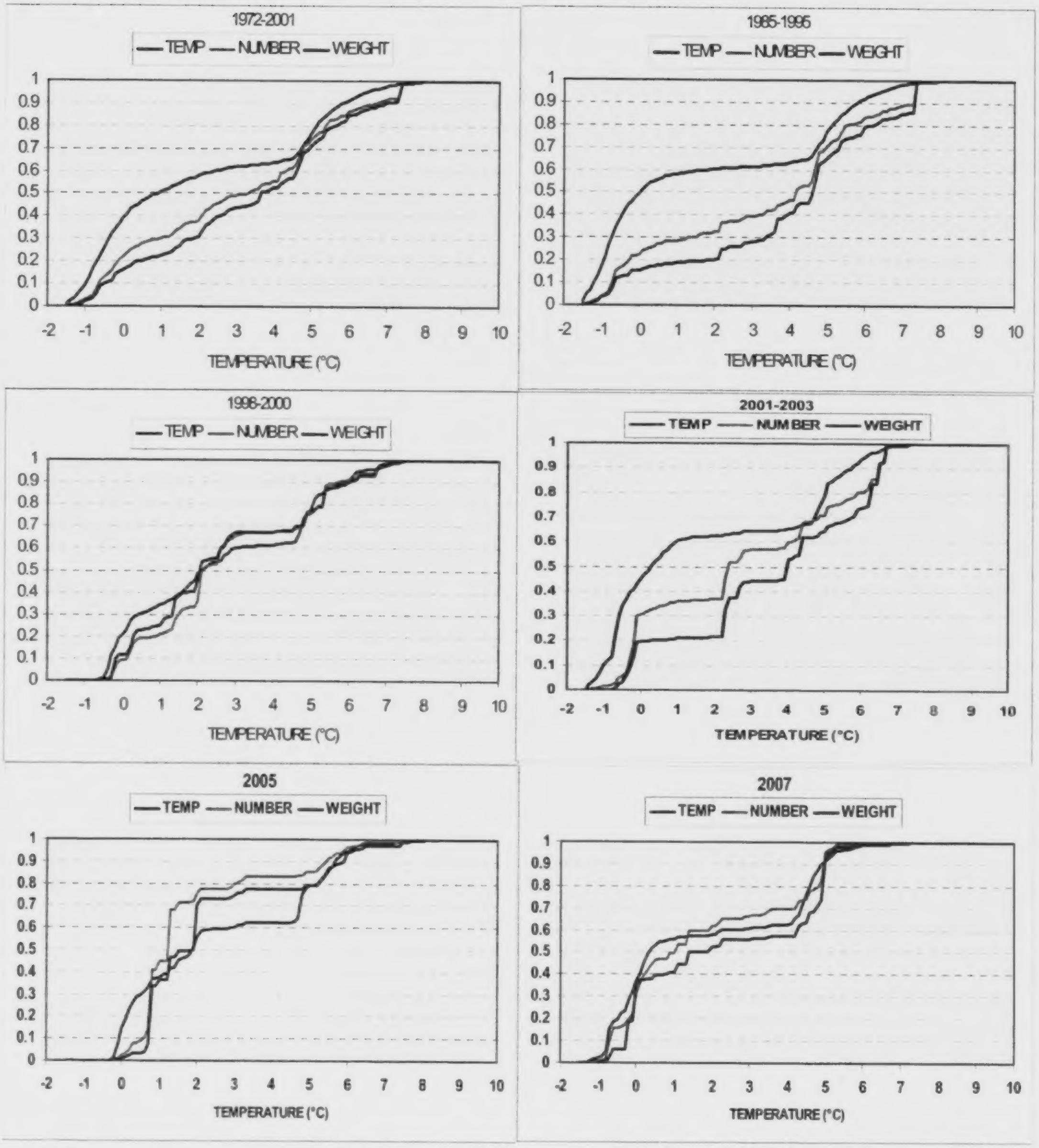


Figure 7. The stratified cumulative frequency distribution of temperature available to cod and the cod number and catch weighted temperature distributions in NAFO Division 3P for the average of 1972-2001, 1985-95 a cold period, 1998-2000 a warm period, 2001-03 a cold period and for 2005 and 2007.

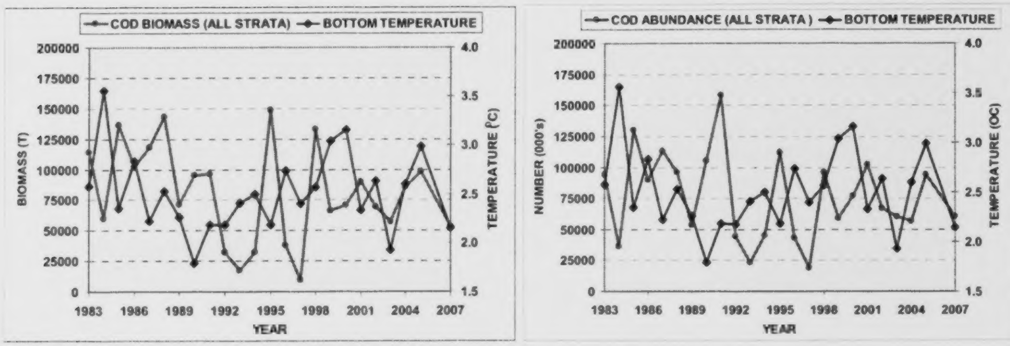


Figure 8. Time series of the mean bottom temperature and the RV abundance and biomass of Atlantic cod for the surveyed area in NAFO Division 3P.

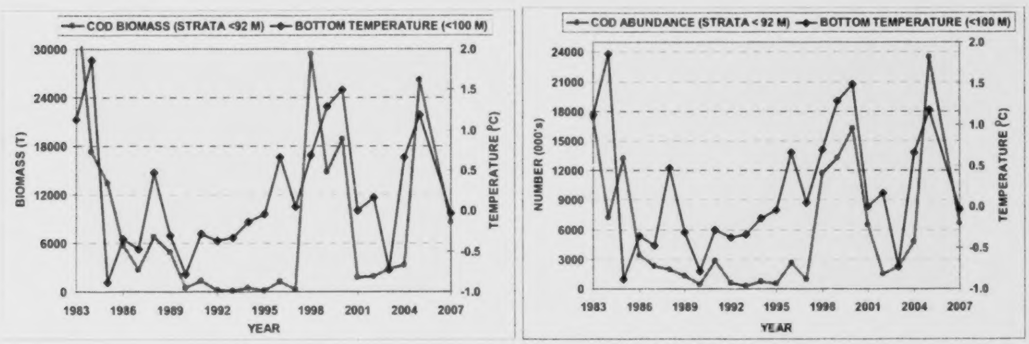
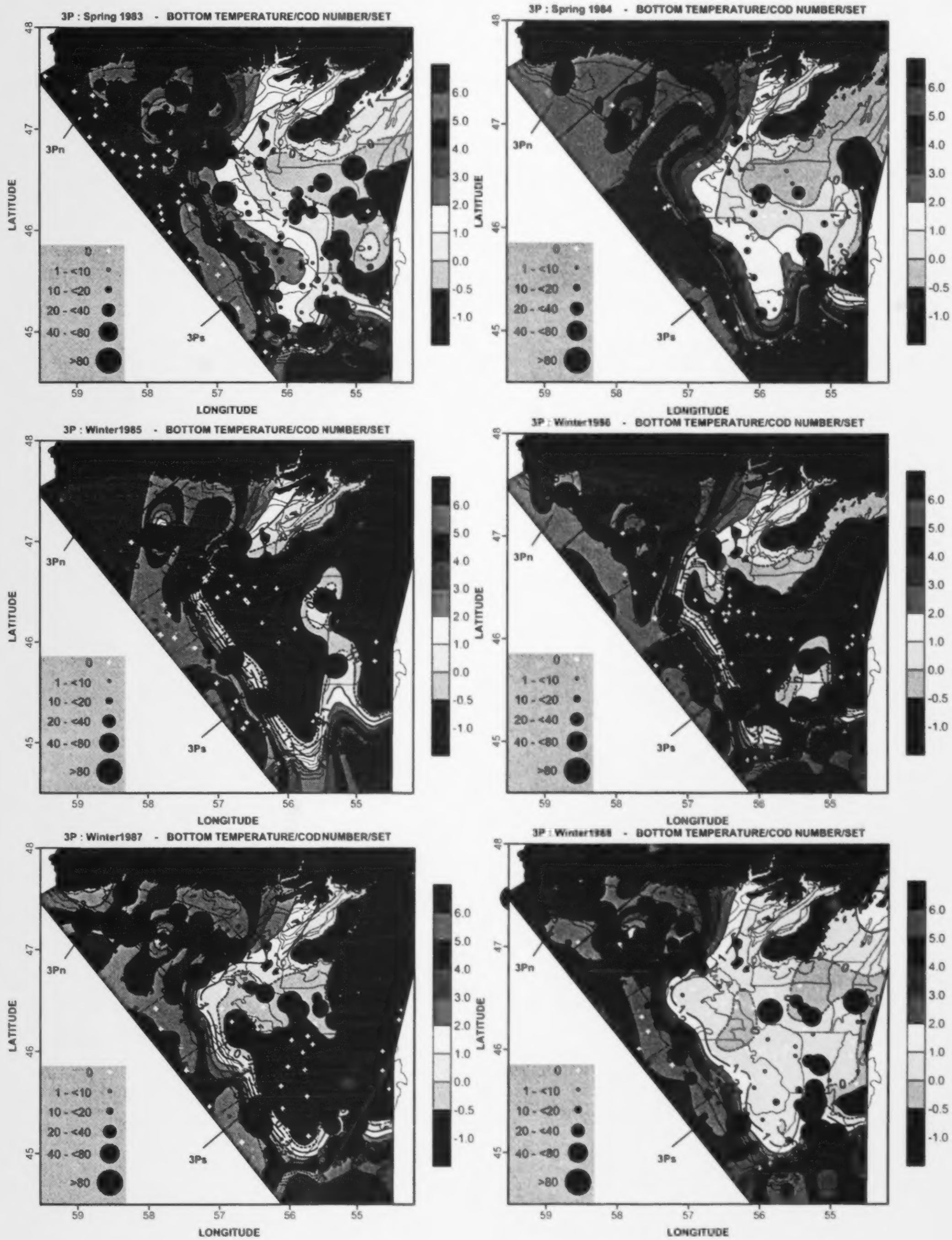
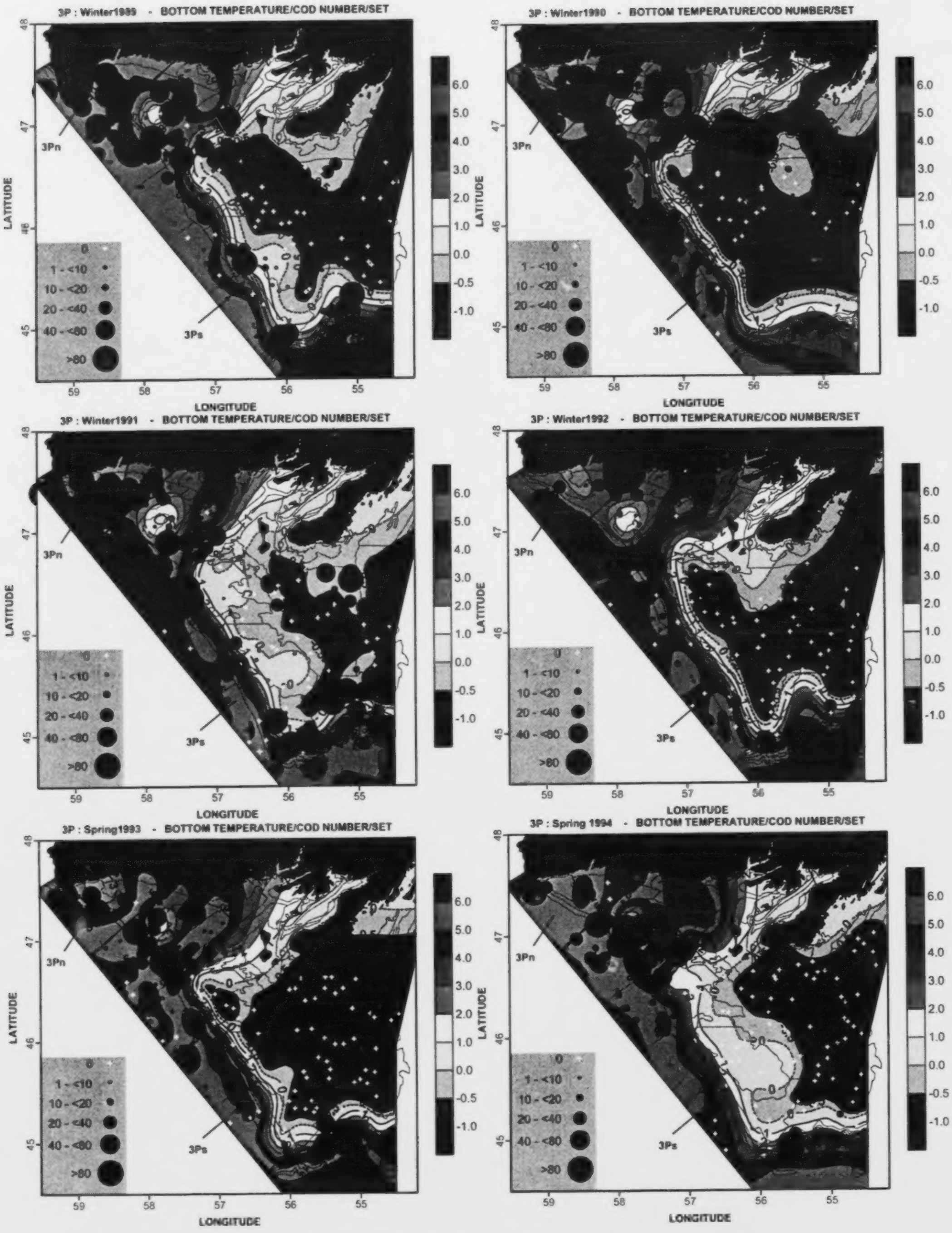
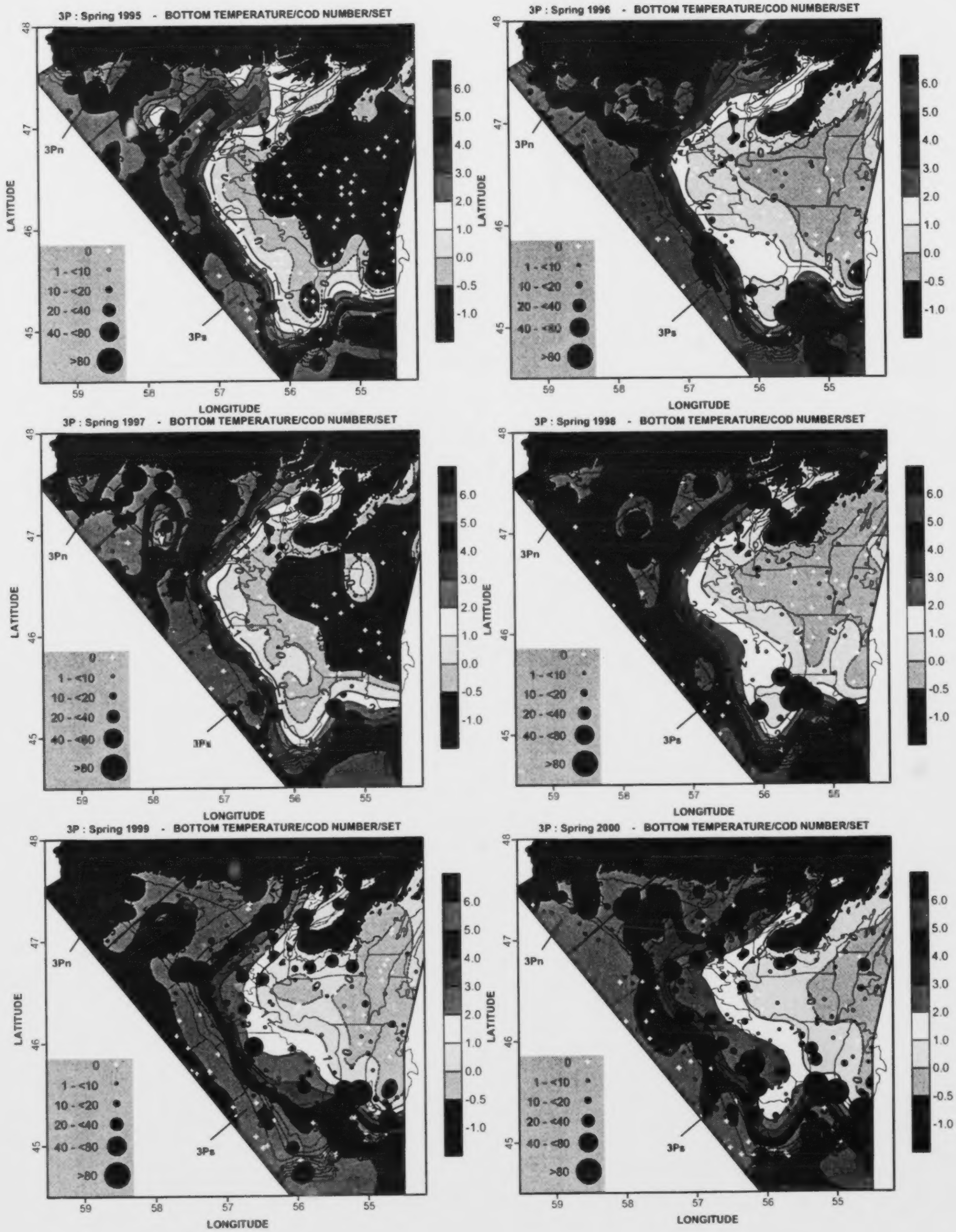


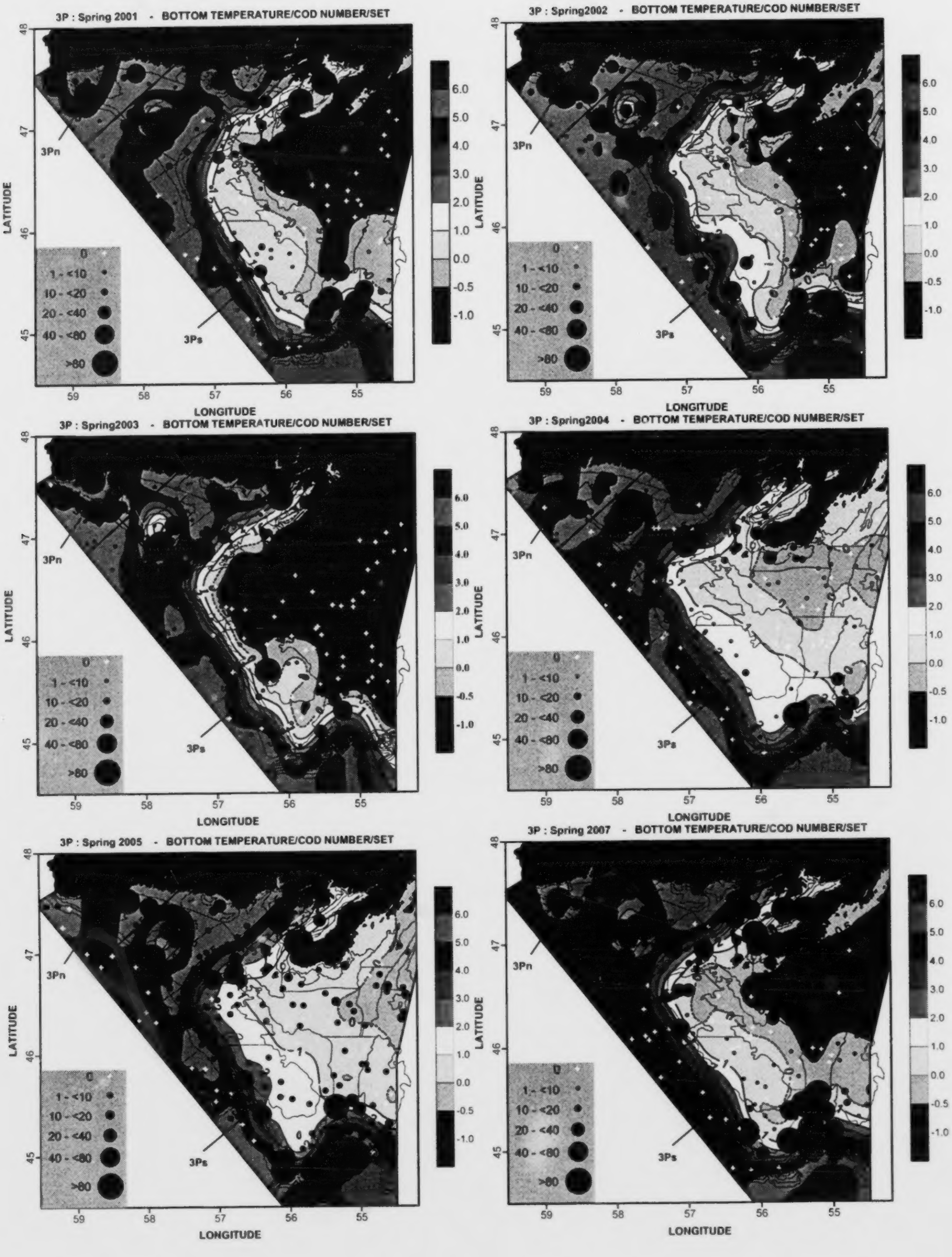
Figure 9. Time series of the mean bottom temperature for water depths <100 m and the RV abundance and biomass of Atlantic cod for the surveyed area in NAFO Division 3P for strata with water depths <92 m.

Appendix 1. 3P cod numbers/set and temperature distribution maps for winter and spring surveys from 1983-2007.




3P : Winter1989 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Winter1990 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Winter1991 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Winter1992 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Spring1993 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Spring 1994 - BOTTOM TEMPERATURE/COD NUMBER/SET
3Pn
3Ps
LATITUDE
LONGITUDE
0
1 - <10
10 - <20
20 - <40
40 - <80
>80
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-0.5
-1.0
48
47
46
45
59
58
57
56
55


3P : Spring 1995 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Spring 1996 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Spring 1997 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Spring 1998 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Spring 1999 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Spring 2000 - BOTTOM TEMPERATURE/COD NUMBER/SET
LATITUDE
LONGITUDE
48
47
46
45
59
58
57
56
55
3Pn
3Ps
0
1 - <10
10 - <20
20 - <40
40 - <80
>80
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-0.5
-1.0


3P : Spring 2001 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Spring2002 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Spring2003 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Spring2004 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Spring 2005 - BOTTOM TEMPERATURE/COD NUMBER/SET
3P : Spring 2007 - BOTTOM TEMPERATURE/COD NUMBER/SET
LATITUDE
LONGITUDE
3Pn
3Ps
0
1 - <10
10 - <20
20 - <40
40 - <80
>80
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-0.5
-1.0